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(54) **LANCE PUMP HAVING VERTICALLY MOUNTED STEPPER MOTOR**

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(73) Assignee: **Lincoln Industrial Corporation**, St. Louis, MO (US)

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F04B 49/06 (2006.01)

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CPC ***F04B 23/028*** (2013.01); ***F04B 49/06*** (2013.01); *F04B 2203/0209* (2013.01); *F04B 2205/05* (2013.01); *F04B 2205/09* (2013.01)

(58) **Field of Classification Search**
CPC . F04B 49/08; F04B 49/065; F04B 2203/0209
USPC 417/44.2, 63, 551.1, 551.2
See application file for complete search history.

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(57) **ABSTRACT**

A pump includes a pump body and an elongate tube. The pump includes an elongate core slidably received in the tube, a stepper motor having a selectively rotatable output shaft extending vertically and a transmission for effecting relative reciprocating motion between the core and the tube. The pump includes an inlet check valve mounted inside the core defining with the core an expansible and contractible lower pump chamber. The inlet check valve is oriented to open during each upward pumping stroke. The pump includes an annular upper chamber above the lower pump chamber and a lateral passage connecting the lower pump chamber to the annular upper chamber. The lateral passage has a check valve oriented to open during each downward pumping stroke. The pump includes an outlet passage connected to the annular upper chamber permitting viscous liquid to flow to the outlet passage on each upward and downward pumping stroke.

10 Claims, 12 Drawing Sheets

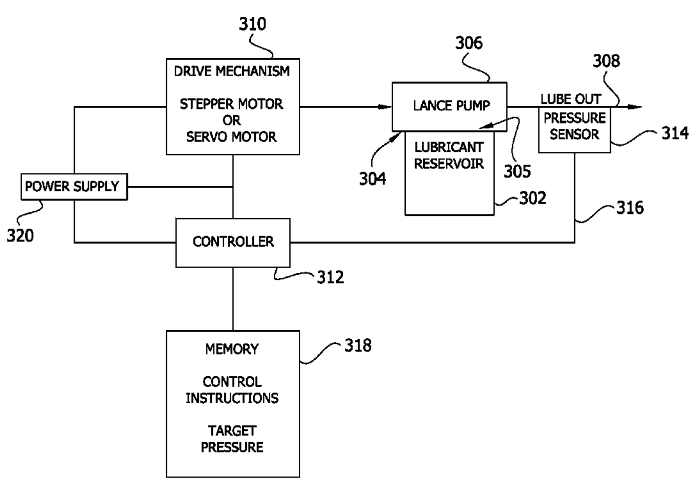

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FIG. 1

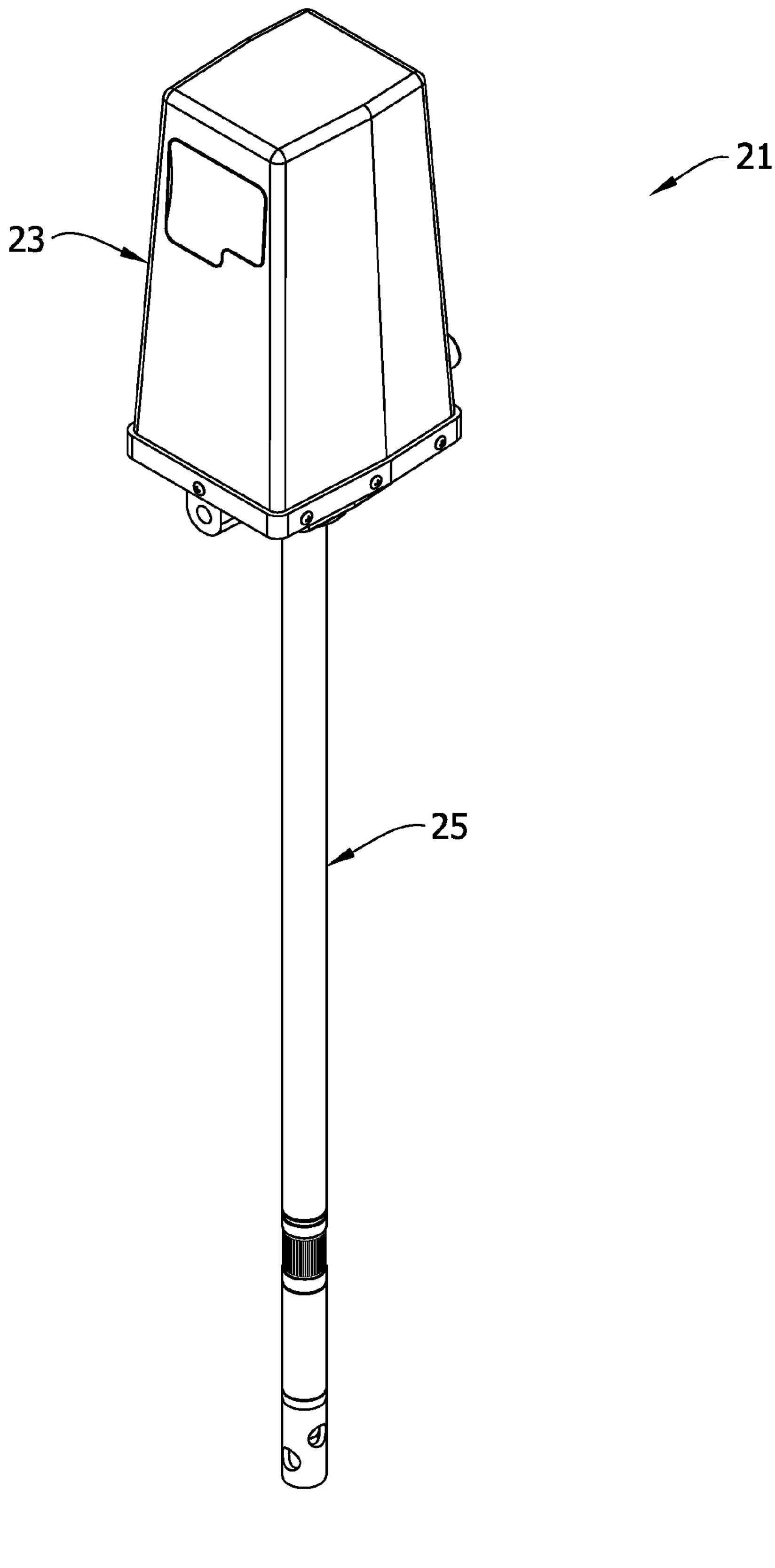
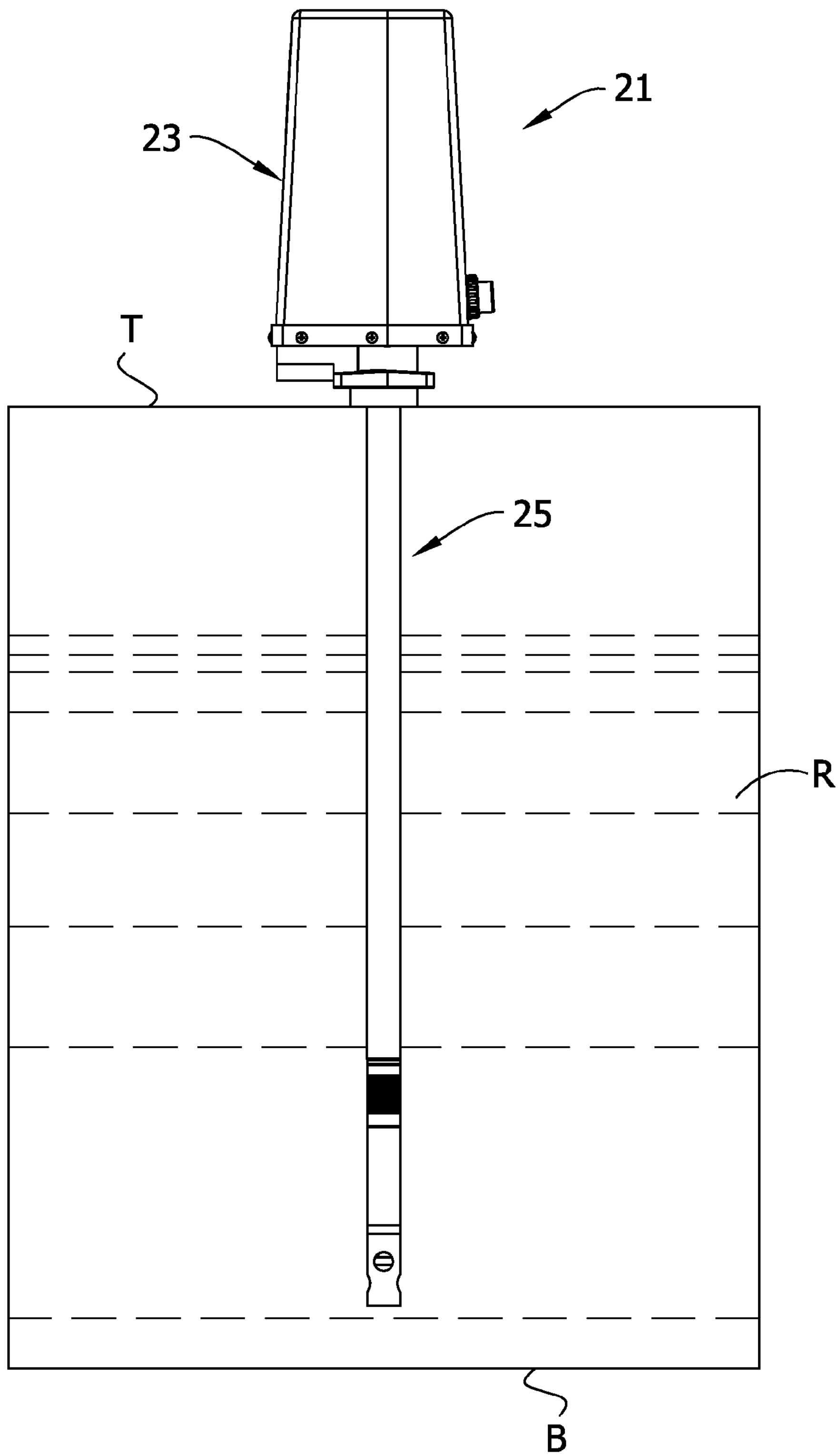


FIG. 2



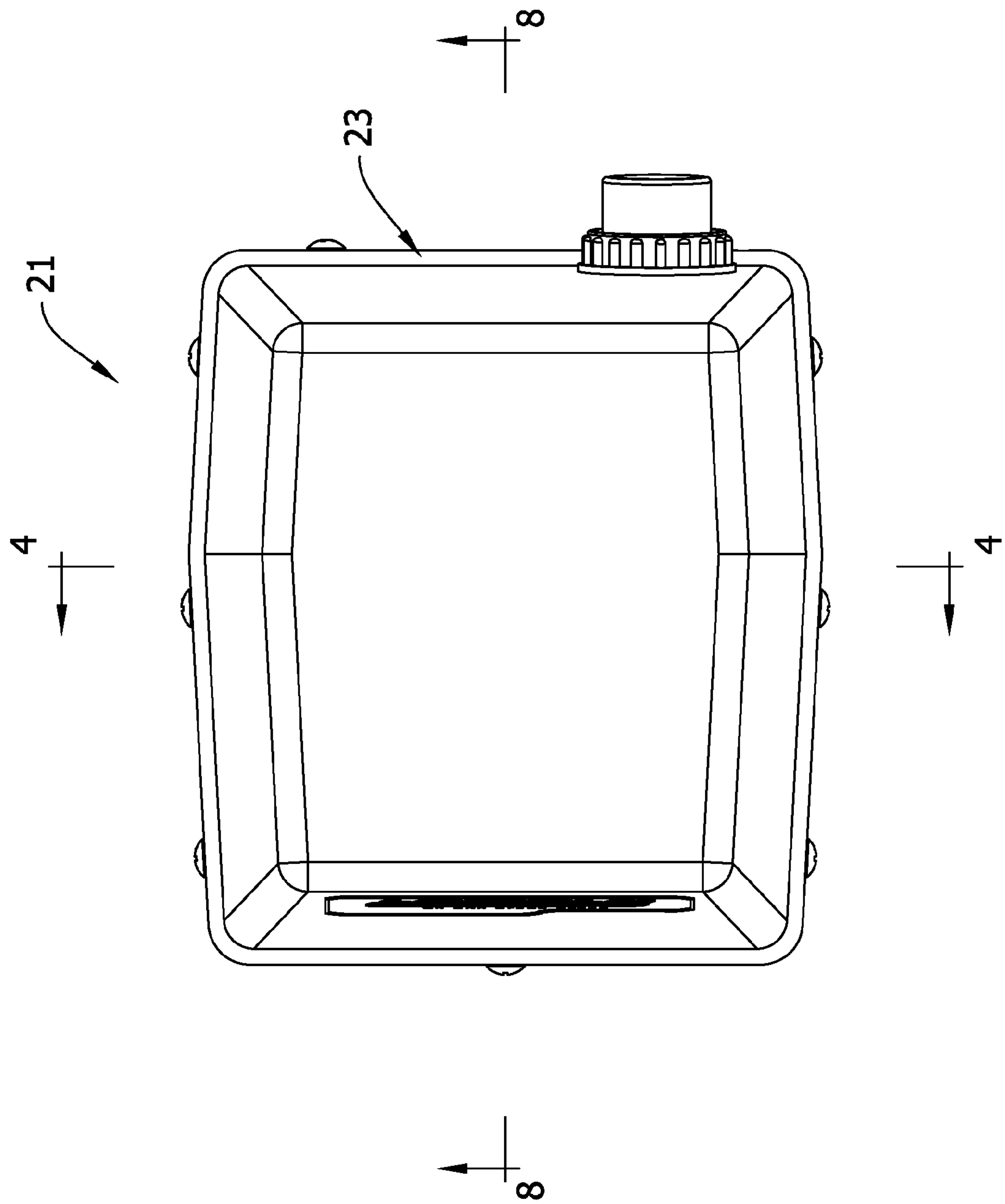
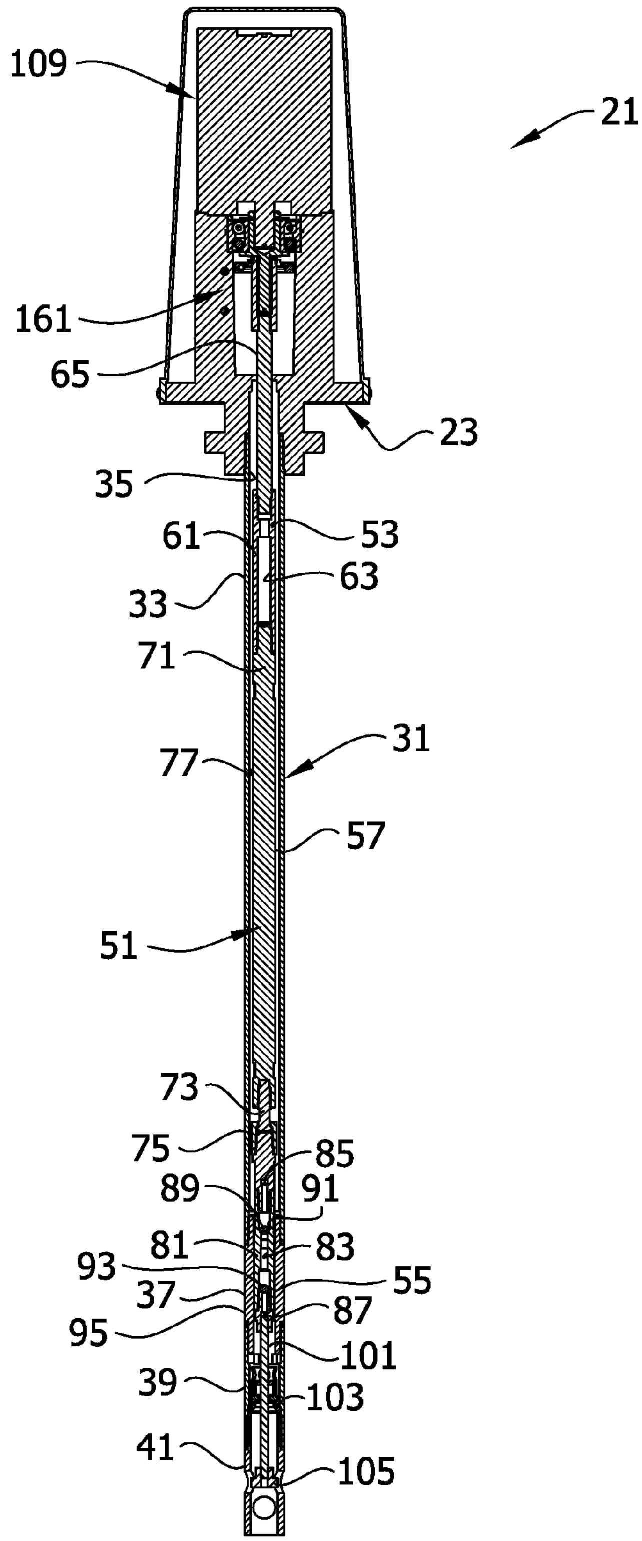


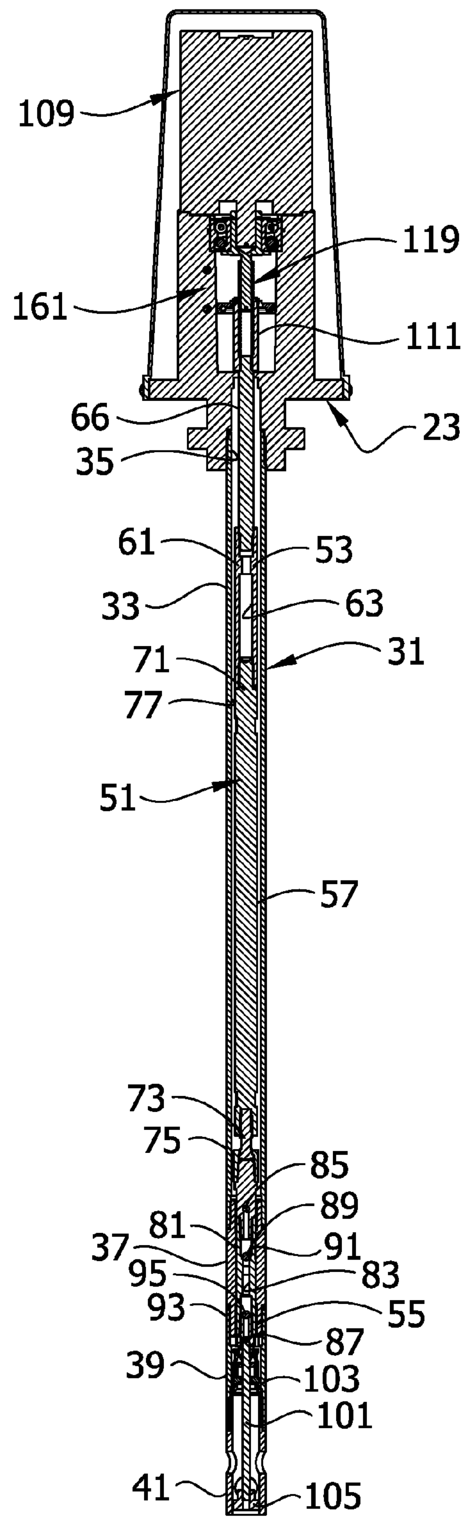
FIG. 3

FIG. 4



109
21
161
65
23
35
61
53
33
63
71
31
77
57
51
73
75
85
89
91
81
83
93
55
37
87
95
101
39
103
41
105

FIG. 5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119
161
111
66
23
35
61
53
33
63
71
31
77
51
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73
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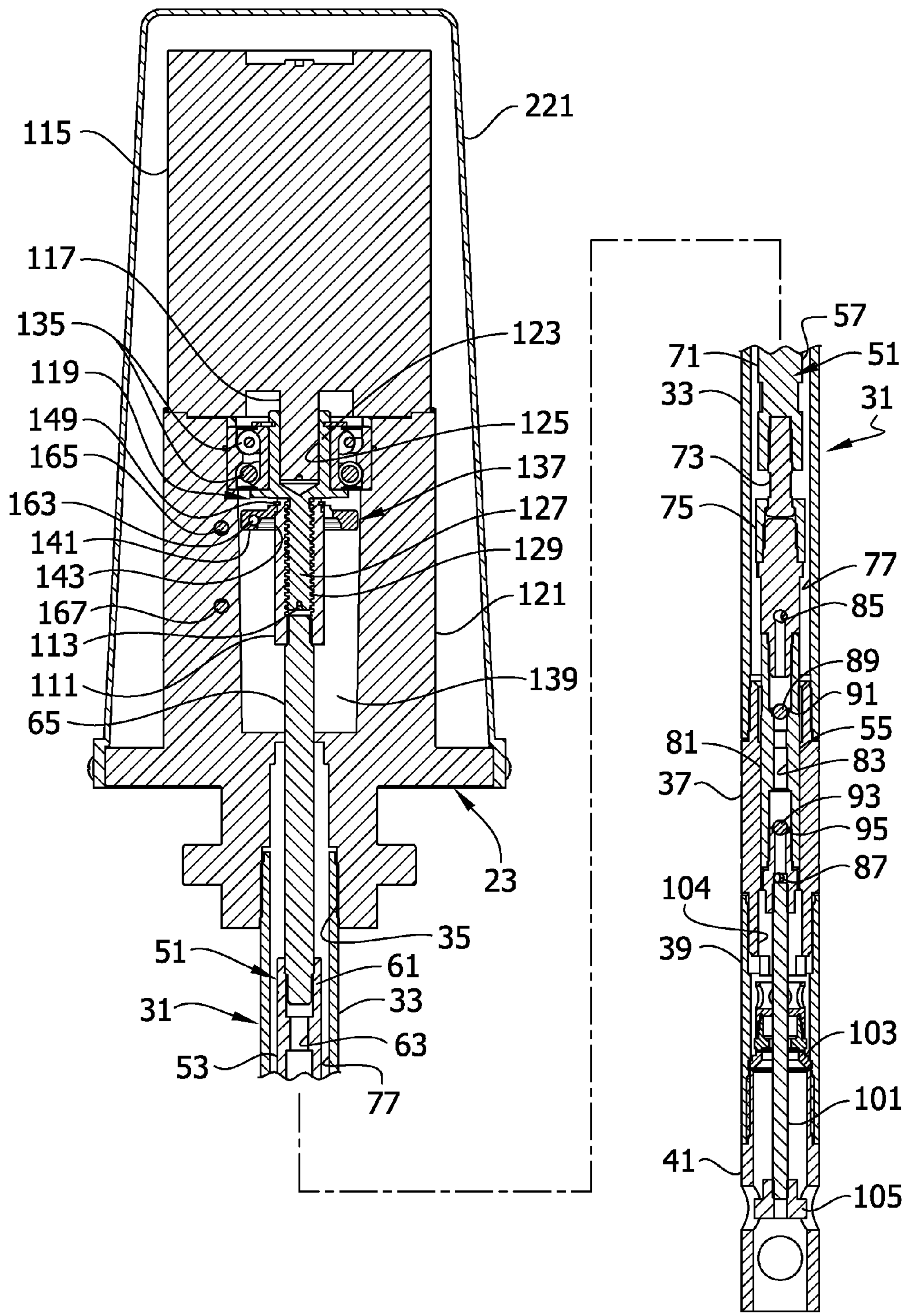
37
91
95
83
93
55
87
39
103
101
41
105

FIG. 6



221
115
117
135
123
119
149
125
165
137
163
127
141
129
143
167
121
113
111
139
65
23
35
51
61
31
33
53
63
77
57
71
51
33
31
73
75
77
85
89
91
55
81
83
37
93
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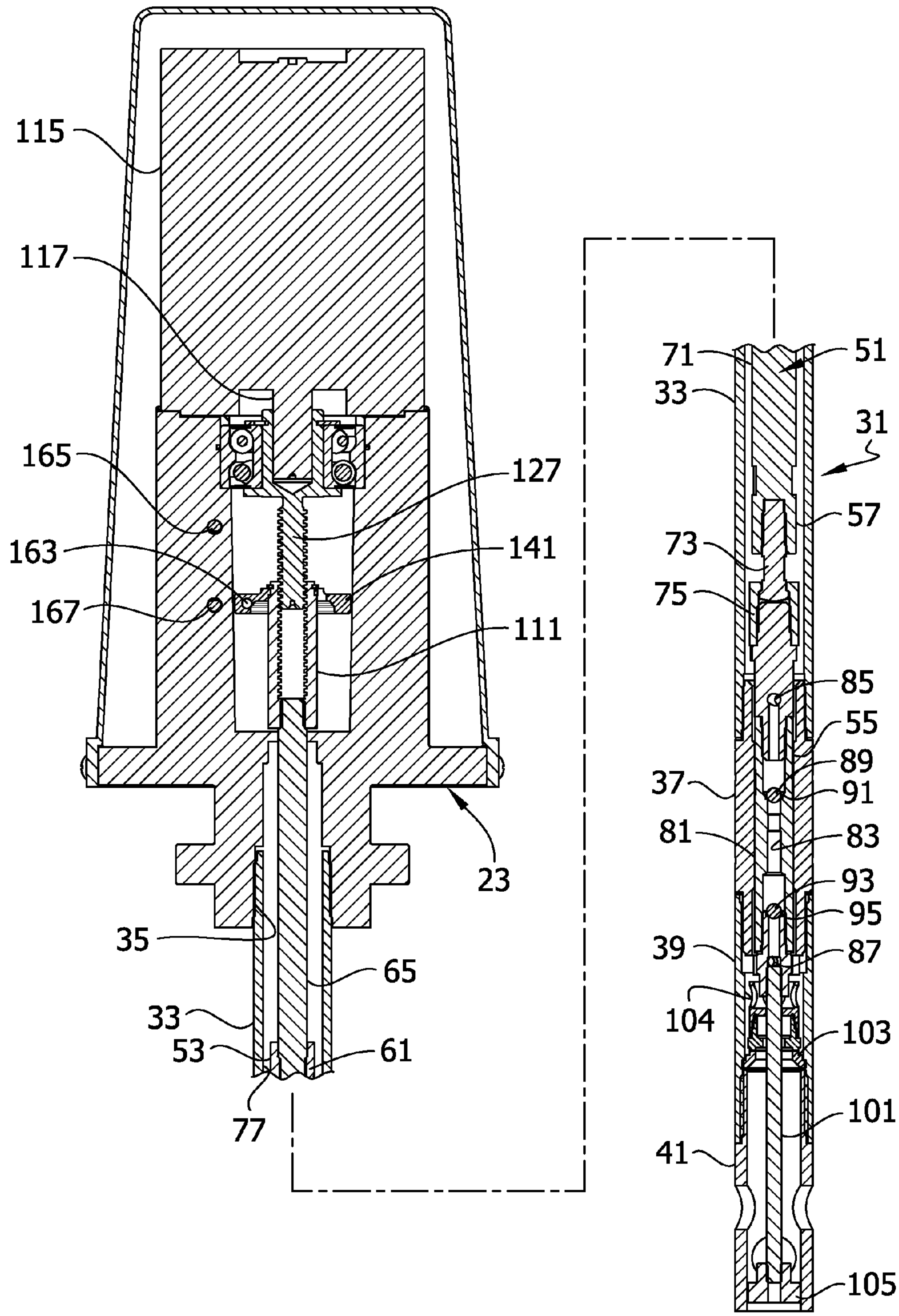
87
104
39
103
101
41
105

FIG. 7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163
167
127
141
111
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65
33
53
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51
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31
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73
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89
37
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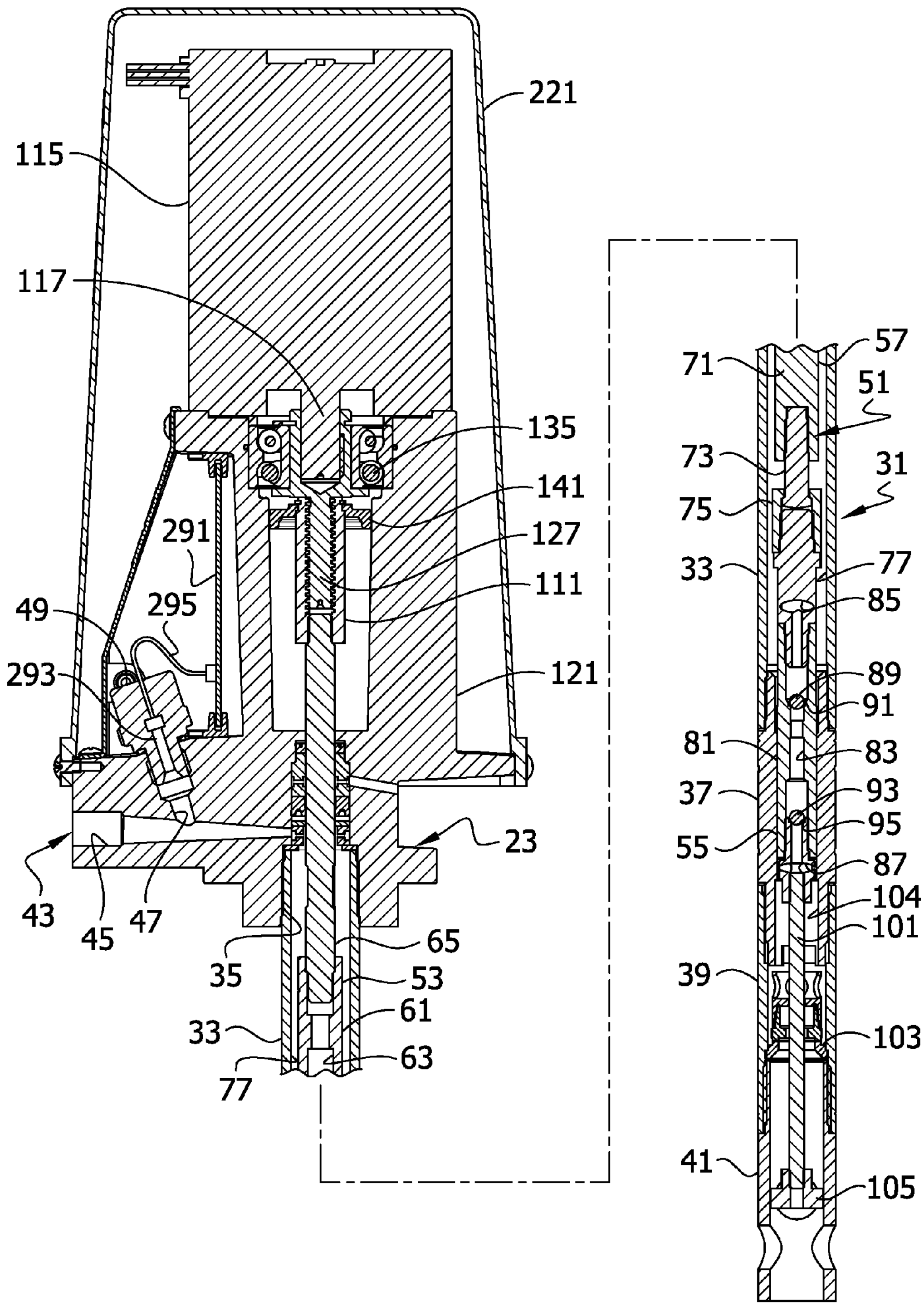
81
83
93
95
39
87
104
103
101
41
105

FIG. 8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141
127
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63
77
57
71
51
73
31
75
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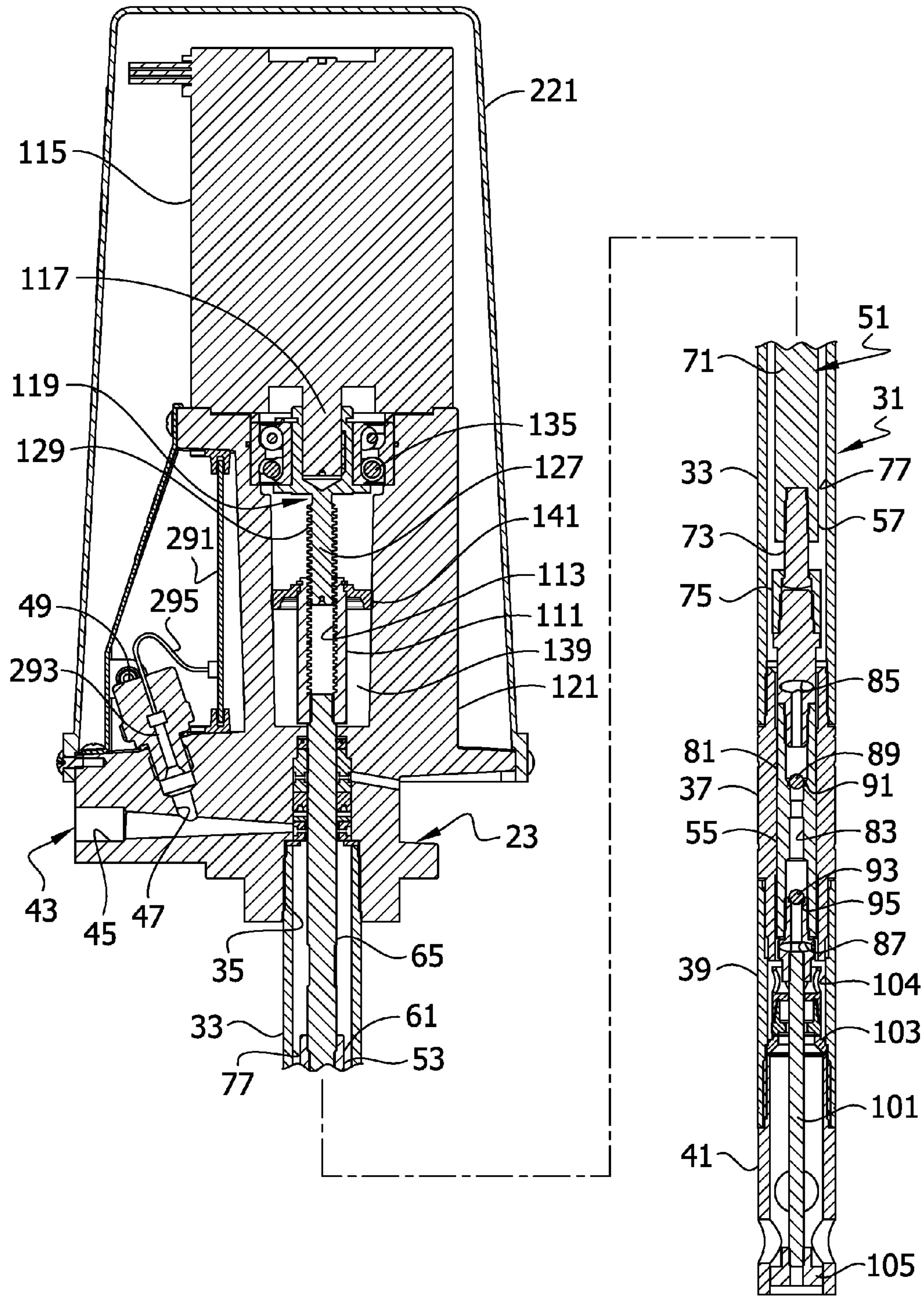
FIG. 9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103
101
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105

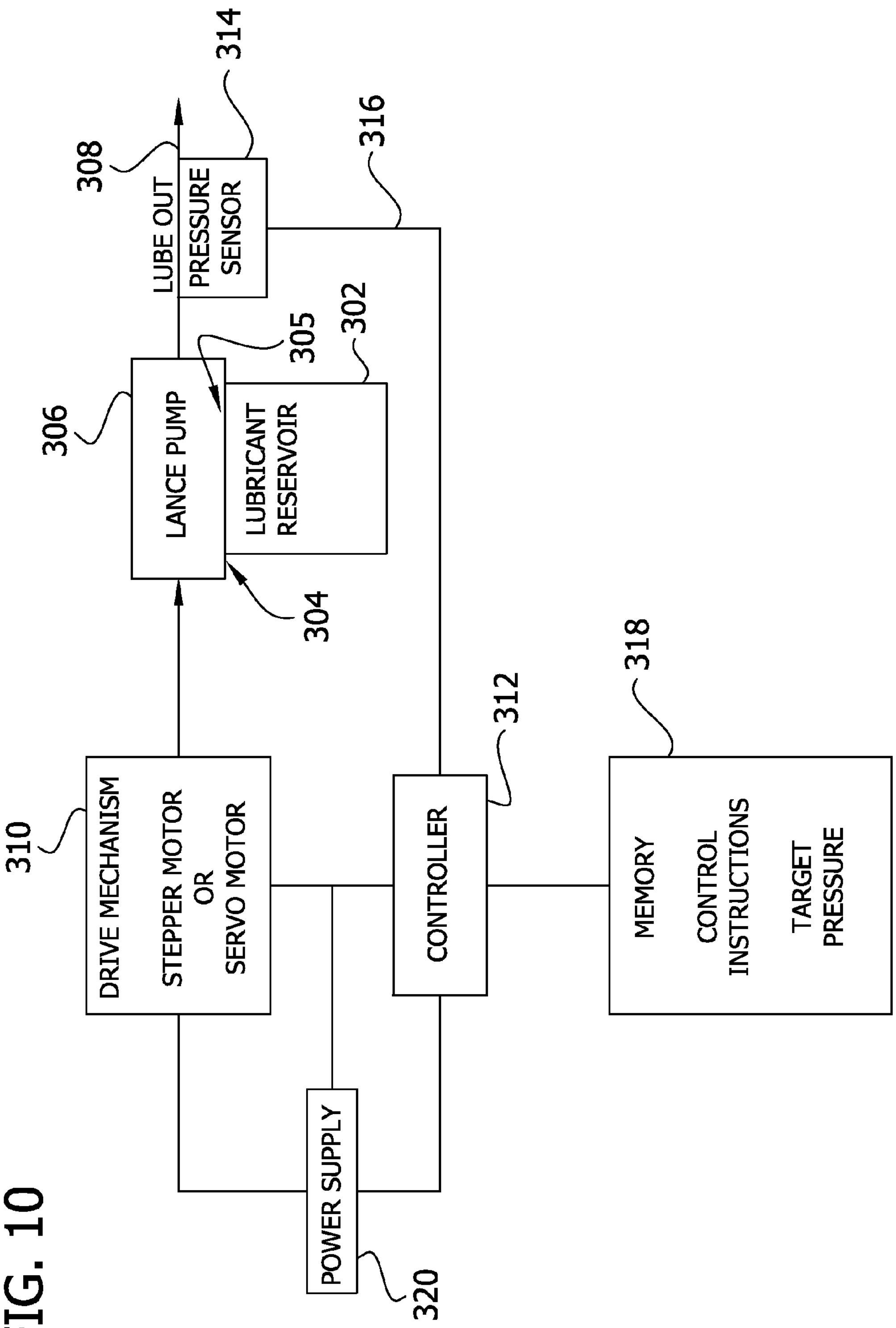

314
308
316
LUBE OUT
PRESSURE
SENSOR
302
305
306
LANCE PUMP
LUBRICANT
RESERVOIR
304
318
312
310
DRIVE MECHANISM
STEPPER MOTOR
OR
SERVO MOTOR
CONTROLLER
MEMORY
CONTROL
INSTRUCTIONS
TARGET
PRESSURE
POWER SUPPLY
320

FIG. 10

FIG. 11

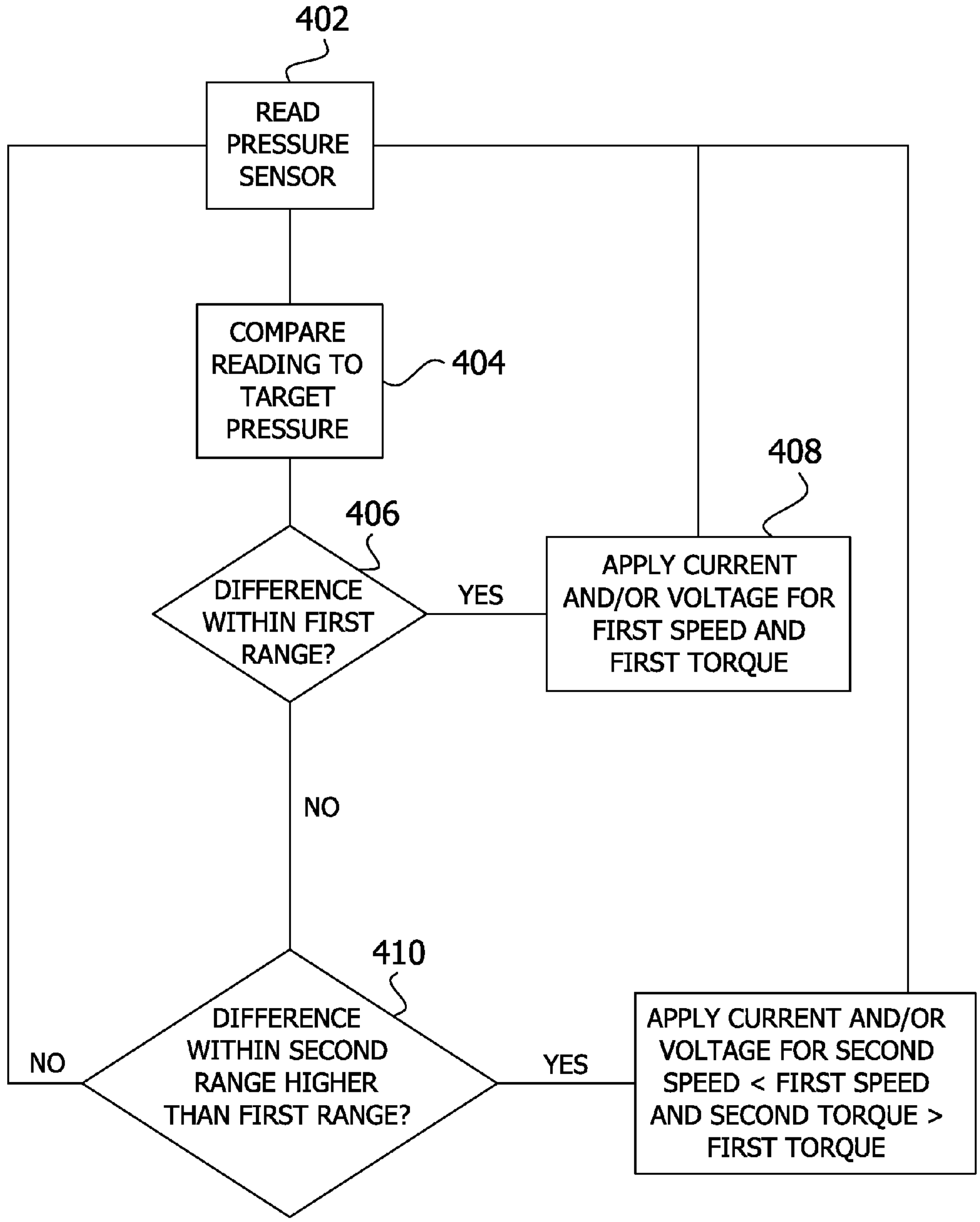
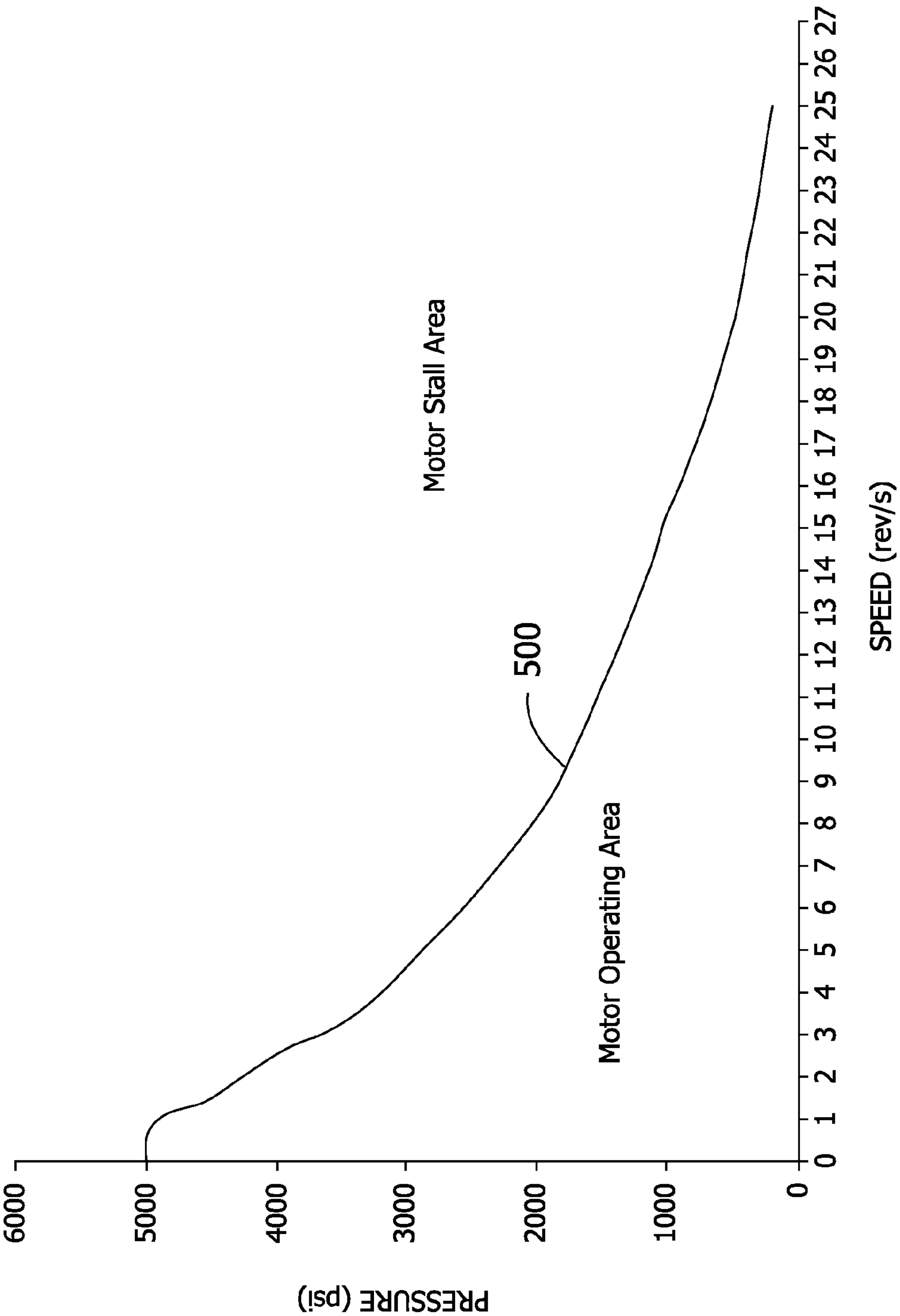

402
READ PRESSURE SENSOR
COMPARE READING TO TARGET PRESSURE
404
406
DIFFERENCE WITHIN FIRST RANGE?
YES
408
APPLY CURRENT AND/OR VOLTAGE FOR FIRST SPEED AND FIRST TORQUE
NO
410
DIFFERENCE WITHIN SECOND RANGE HIGHER THAN FIRST RANGE?
NO
YES
APPLY CURRENT AND/OR VOLTAGE FOR SECOND SPEED < FIRST SPEED AND SECOND TORQUE > FIRST TORQUE

FIG. 12


Motor Stall Area
500
Motor Operating Area
PRESSURE (psi)
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
SPEED (rev/s)

LANCE PUMP HAVING VERTICALLY MOUNTED STEPPER MOTOR

FIELD OF THE INVENTION

This invention relates to pumps, and more particularly to an expansible chamber pump of a type which may be referred to as a lance pump or drum pump, particularly adapted for pumping lubricant, including grease, from a supply thereof (e.g., lubricant in a drum).

BACKGROUND OF THE INVENTION

The pump of this invention is in the same field as the pumps shown in the following U.S. Pat. Nos. 2,187,684; 2,636,441; 2,787,225; 3,469,532; 3,502,029; 3,945,772; 4,487,340; 4,762,474; and 6,102,676. Of particular interest is U.S. Pat. No. 2,787,225, which is directed to a lance pump sold by Lincoln Industrial Corporation of St. Louis, Mo., under the designation Series 20. Although lance pumps such as those identified above have been commercially successful, there is a need for a pump that provides a selectively variable output pressure and reduces disassembly and assembly complexity.

SUMMARY OF THE INVENTION

In one aspect, the present invention includes a pump for pumping a viscous liquid from a reservoir. The pump comprises a pump body adapted for positioning above the reservoir and an elongate tube extending downward from an upper end connected to the body, past an upper portion and a lower portion, to a lower end when the body is positioned above the reservoir. An elongate core slidably received in the tube extends vertically downward from the body into the liquid when the body is in position above the reservoir. The core has a longitudinal axis extending between an upper end mounted on the body for vertical reciprocating motion and a lower end opposite the upper end. Further, the pump includes a stepper motor mounted on the body having a selectively rotatable output shaft extending vertically above the liquid in the reservoir when the body is in position and a transmission operatively connected to the stepper motor output shaft. The transmission effects reciprocating relative motion between the tube and the core so the elongate core moves between a relative raised position and a relative lowered position as the stepper motor output shaft rotates in one direction to effect an upward pumping stroke and in an opposite direction to effect a downward pumping stroke. In addition, the pump has an inlet check valve mounted inside the core defining with the core an expansible and contractible lower pump chamber. The inlet check valve is oriented to open during each upward pumping stroke permitting viscous liquid to enter the lower pump chamber. The pump also comprises an annular upper chamber defined in part by the tube and the core above the lower pump chamber and a lateral passage in the core connecting the lower pump chamber to the annular upper chamber. The lateral passage has a check valve oriented to open during each downward pumping stroke. The pump includes an outlet passage connected to the annular upper chamber permitting viscous liquid to flow from the annular upper chamber to the outlet passage on each upward and downward pumping stroke.

In another aspect, the present invention includes a pump for pumping a viscous liquid from a reservoir. The pump comprises a pump body adapted for positioning above the reservoir and an elongate tube extending downward from an upper end connected to the body to a lower end below the upper end when the body is positioned above the reservoir. The pump also includes an elongate core slidably received in the tube and extending vertically downward from the body into the liquid when the body is in position above the reservoir. The core has a longitudinal axis extending between an upper end mounted on the body and a lower end opposite the upper end. In addition, the pump comprises an electric motor mounted on the body having a selectively rotatable output shaft for effecting relative reciprocating motion between the core and the elongate tube so the core moves between a relative raised position and a relative lowered position as the motor output shaft rotates in one direction to drive the pump through an upward pumping stroke and in an opposite direction to drive the pump through a downward pumping stroke. The pump also includes a control operatively connected to the electric motor for controlling operation of the motor and an inlet check valve mounted inside the core defining with the tube an expansible and contractible lower pump chamber. The inlet check valve is oriented to open during each upward pumping stroke permitting viscous liquid to enter the lower pump chamber. Further, the pump includes an annular upper chamber defined in part by the tube and the core above the lower pump chamber and a lateral passage in the core connecting the lower pump chamber to the annular upper chamber. The lateral passage has a check valve oriented to open during each downward pumping stroke to deliver viscous liquid from the lower pump chamber to the annular upper chamber. The pump comprises an outlet passage connected to the annular upper chamber permitting viscous liquid to flow from the annular upper chamber.

Other objects and features will be in part apparent and in part pointed out hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective of a lance pump of one embodiment of the present invention;

FIG. **2** is a side elevation of the lance pump mounted on a supply of lubricant;

FIG. **3** is a top plan of the pump in FIG. **1**;

FIG. **4** is a vertical section taken in the plane of line **4-4** of FIG. **3** showing a pump core in a raised position;

FIG. **5** is a vertical section similar to FIG. **4** but showing the core in a lowered position;

FIG. **6** is a detail of FIG. **4** showing a pump core in a raised position;

FIG. **7** is a detail of FIG. **5** showing a pump core in a lowered position;

FIG. **8** is a detail similar to FIG. **6** but taken in the plane of line **8-8** of FIG. **3**;

FIG. **9** is a detail similar to FIG. **8** but showing the core in a lowered position;

FIG. **10** is a block diagram illustrating a control controlling a motor such as a servo motor or a stepper motor driving a lance pump according to one embodiment of the invention;

FIG. **11** is a flow chart illustrating operation of a control controlling a motor such as a servo motor or a stepper motor driving a lance pump according to one embodiment of the invention; and

FIG. **12** is a graph illustrating pressure in psi vs. speed in rpm of a stall curve of the motor.

Corresponding reference characters indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION

Referring to FIGS. **1-3**, a lance pump or drum pump of the present invention, constructed particularly for pumping lubricant, especially grease, from a supply, is designated in its entirety by the reference number **21**. The pump **21** comprises a pump body, generally designated by **23**, adapted for placement above the supply, and a lance structure, generally designated by **25**, extending down from the body. The lance structure **25** is intended to extend into a supply of lubricant. As indicated in FIG. **2**, the supply may be contained in a reservoir R, such as a drum, the body being mounted on the top or lid T of the drum with the lance structure **25** extending down into the drum toward the bottom B of the reservoir through a hole in the top. Although the pump **21** has been developed for pumping lubricant and especially grease, it is adapted to pump other pumpable products, particularly viscous liquids.

Referring to FIGS. **4-9**, the pump **21** comprises an elongate pump tube, designated in its entirety by the reference numeral **31**, extending down from an upper end fixedly connected to the body **23** to a lower end extending into the reservoir R when the pump is mounted on the top T. The pump tube **31** includes an upper tubular member **33** received in a bore **35** of the body **23**, an intermediate tubular member **37** attached to a lower end of the upper tubular member opposite the body, a tubular extension member **39** attached to a lower end of the intermediate tubular member opposite the upper tubular member, and a priming tube **41** with one or more openings **42** attached to a lower end of the tubular extension member opposite the intermediate tubular member. The components of the pump tube **31** can be attached in any one of several conventional ways, such as by threaded connection. The upper tubular member **33**, intermediate tubular member **37**, tubular extension member **39**, and priming tube **41** are co-linear on a vertical central axis of the lance structure **25**. The pump tube **31** has a substantially uniform outer diameter, such that there is a smooth transition between the separate components of the pump tube.

As illustrated in FIGS. **8** and **9**, the body **23** has an outlet passage, generally designated by **43**, in fluid communication with the bore **35**. The outlet passage **43** includes a generally tapered portion **45** adapted to dispense viscous liquid from the pump, and a branch **47** extending at an angle from the tapered portion. The branch **47** of the outlet passage **43** holds a plug **49** capable of monitoring pressure, as will be explained below.

As further shown in FIGS. **4-9**, an elongate member constituting a pump rod or core, designated in its entirety by the reference numeral **51**, extends down from the body **23** and is slidably received in the pump tube **31**. The core **51** has an upper end portion **53**, a lower end portion **55** and an intermediate portion **57**. These portions **53**, **55**, **57** are co-linear on a vertical central axis of the lance structure **25**.

As shown in FIGS. **4-6**, the upper end portion **53** of the core **51** comprises a relatively short tubular element **61** having a bore **63** extending from its lower end to its upper end. The upper end of the tubular element **61** is connected to a lower end of a piston rod **65**. The tubular element **61** has an outer diameter less than the outer diameter of the piston rod **65**. The piston rod **65** extends from a lower end connected to the tubular element **61** through the bore **35** of the body **23** to an upper end connected to a drive mechanism, as will be explained in further detail below. The lower end of the tubular element **61** is connected to the intermediate portion **57** of the elongate core **61**, such as by threaded connection. The intermediate portion **57** of the pump core **51** comprises an elongate solid cylindrical core member or rod **71** considerably longer than the tubular element **61**. A lower end of the solid core member **71** comprises a stem **73** and a sleeve **75** attaching the stem to an upper end of the lower end portion **55** of the pump core **51**. The tubular element **61** and the solid core member **71** are both received in the upper tubular member **33** of the pump tube **31**. An annular upper chamber **77** is defined between the pump tube **31** and the pump core **51**. Particularly, in the illustrated embodiment, the annular upper chamber **77** is defined between the upper tubular member **33** and the pump core **51**. The annular upper chamber **77** is in fluid communication with the outlet passage **43** to facilitate dispensing liquid, as described below.

The lower end portion **55** of the pump core **51** comprises a plunger **81** slidingly and sealingly received in the intermediate tubular member **37**. The plunger **81** includes a longitudinal passage **83** extending between an upper lateral passage **85** and a lower lateral passage **87**. A check valve ball **89** is located below the upper lateral passage **85** and rests in a seat **91**. Another check valve ball **93** is located above the lower lateral passage **87** and rests in a seat **95**. A shovel rod **101** extends downward from the lower end of the plunger **81** through a priming or inlet check valve **103** located in the tubular extension member **39** and into the priming tube **41**. The space between the seat of the inlet check valve **103** and the lower end of the pump core **51** defines a lower chamber **104**. The shovel rod **101** is slidable with respect to the inlet check valve **103**. A shovel **105** is attached to a lower end of the shovel rod **101** and is configured for reciprocating movement with the shovel rod within the priming tube **41**.

As will be described hereinafter, the upper and lower chambers **77**, **104** are expansible and contractible chambers which expand and contract during upstrokes and downstrokes of the piston rod **65** and pump core **51**. (The lower chamber **104** contracts and the upper chamber **77** expands during a downstroke; the lower chamber expands and the upper chamber contracts during an upstroke.) As a result, fluid is delivered through the outlet passage **43** during both upstrokes and downstrokes of the pump.

A motor-driven transmission, indicated generally at **109**, is mounted on the body **23** for reciprocating the pump core **51** through a pump stroke. The transmission **109** reciprocates the pump core **51** between a raised position relative to the fixed pump tube **31** and a lowered position relative to the pump tube. The pump core **51** moves toward the raised position during an upstroke, as illustrated in FIGS. **4**, **6**, and **8**, and moves toward the lowered position during a downstroke, as illustrated in FIGS. **5**, **7**, and **9**.

As illustrated in FIGS. **6-9**, the piston rod **65** is attached to an upper end of the pump core **51** and to a lower end of a hollow cylindrical piston body **111** opposite the pump core. The piston body **111** has internal threads **113** extending from generally adjacent the upper end of the body toward the lower end of the body, but desirably terminating short of the lower end.

The pump core **51** is movable through up and down pumping strokes by reciprocating movement of the piston rod **65**. The piston rod **65** is movable in a reciprocating manner by a linear position drive mechanism comprising a stepper motor **115** having a vertical output shaft **117** connected to a co-axial lead screw, generally designated by **119**, rotatable in a follower housing portion **121** of the body **23**. The lead screw **119** comprises a lead screw body **123** having a bore **125** that receives the output shaft **117** of the stepper motor **115**, and a threaded shaft **127** extending downward from the lead screw body. The shaft **127** has external threads **129** configured to mate with the internal threads **113** of the piston body **111**. The stepper motor output shaft **117** engages the body **123** of the lead screw (e.g., with a spline connection) so that the shaft and the lead screw turn in unison. Desirably, the mating threads on the piston body and lead screw are constructed for the efficient transmission of power. By way of example, the threads **113**, **129** may be full ACME threads capable of carrying a substantial load for pumping liquid at high pressures. Thrust loads exerted on the piston and the lead screw are carried by angular contact bearings **135**. The angular contact bearings **135** support loads in both directions, i.e., during both the upstroke and the downstroke.

A follower, generally designated by **137**, is secured to the piston body **111** for back and forth linear movement of the follower and the piston body in a cavity **139** in the follower housing portion **121** of the body **23**. The longitudinal centerline of the cavity **139** is generally co-axial with the longitudinal centerlines of the piston body **111** and the lead screw **119**. The longitudinal centerline of the cavity **139** is also co-axial with the longitudinal centerline of the piston rod **65** and the bore **35** extending through the hollow body **23**. The piston rod **65** extends from a location within the cavity **139** through the bore **35** and into the pump tube **31**.

The follower **137** comprises a follower body **141** having a central opening **143** that receives an upper end portion of the piston body **111**. Desirably, the follower body **141** has a non-circular peripheral shape conforming to a non-circular cross-sectional shape of the cavity **139** to prevent rotational movement of the follower as it reciprocates in the cavity. The central opening **143** of the follower bore and the upper end portion of the piston body **111** can be non-circular in shape (e.g., rectangular) to prevent relative rotational movement between the piston and the follower. The follower **137** is held in place against a shoulder on the piston body **111** by a retaining clip **149**. Other constructions may be used to prevent relative rotation and linear movement between the piston and the follower without departing from the scope of the present invention. Rotation of the motor output shaft **117** and lead screw **119** in one direction causes the piston rod **65** to move linearly in the bore **35** through a pumping upstroke, and rotation of the output shaft and lead screw in the opposite direction causes the piston rod to move linearly in the bore through a pumping downstroke. The lengths of the pumping upstrokes and downstrokes are controlled by operation of the stepper motor **115**, which is under the control of a control, as will be described further below. Desirably, the cavity **139** functions as a reservoir for holding a lubricant (e.g., oil) suitable for lubricating the threads **113**, **129** on the piston body **111** and the lead screw **119**.

A calibration mechanism generally designated **161** is provided for calibrating operation of the stepper motor **115** relative to the position of the piston body **111** in the cavity **139**. In the illustrated embodiment, this mechanism **161** comprises a magnet **163** on the follower **137** movable with the piston body **111**, and at least one and desirably two magnetic field sensors **165**, **167** mounted on the follower housing portion **121** at spaced-apart locations corresponding to the piston movement. The control receives signals from the calibration mechanism **161** and calibrates operation of the stepper motor relative to the position of the piston.

The pump body **23** can be contained in a housing **221**. Furthermore, as illustrated in FIGS. **8** and **9**, a control **291** is provided in or on the housing **221** for controlling operation of the stepper/servo motor **115**. In particular, the control **291** is a microprocessor custom made by Lincoln Industrial Corporation of St. Louis, Mo., and is adapted to control a speed and direction of rotation of the output shaft **117** of the motor **115**. As will be appreciated by those skilled in the art, the control **291** operates to change the flow rate of lubricant being pumped from the supply R. A pressure transducer **293** (broadly, a pressure monitor) mounted in the plug **49** is operatively connected by an electrical lead **295** to the control **291**. In one embodiment, the transducer is a No. 846F-A-6000-00 available from Hydac Technology Corporation of Bethlehem, Pa. The transducer **293** communicates with the bore of the outlet passage **43** to measure pressure in the bore. When pressure of fluid in the bore is outside a predetermined range, the control **291** adjusts the speed of the motor **115** to adjust the flow rate of lubricant being pumped and thereby adjust the pressure of fluid in the bore of the outlet passage **43**. For example, when the pressure falls below the predetermined range, the control **291** increases the speed of the motor **115** to increase the flow rate of lubricant, thereby increasing the pressure of fluid in the bore of the outlet passage **43**. Although the control **291** may operate to maintain the pressure of lubricant in the bore to be within other predetermined ranges, in one embodiment the control maintains the pressure to be within a range of about 1000 psi to about 5000 psi. As will be appreciated by those skilled in the art, the control **291** can control system pressures to be within good design limits.

To begin an upstroke, the control operates the stepper motor **109** to rotate its output shaft **117** in one direction, causing the piston rod **65** and pump core **51** to move upward from the position shown in FIG. **7** to the position shown in FIG. **9**. As the pump core **51** rises, the lower chamber **104** expands to draw fluid from the reservoir R through the openings **42** in the priming tube **41**, past the shovel **105**, and up into the lower chamber. During this movement, the check valves **89**, **93** remain closed, and the volume of the upper chamber **77** decreases to force an amount of fluid in that chamber through the outlet passage **43**. (The decrease in volume is due to the fact that the relatively smaller diameter piston rod **65** moves up out of the upper chamber **77**.) In the illustrated embodiment, the plunger **81** has a diameter of about 0.5 inch. Although the piston rod **65** may have other diameters without departing from the scope of the present invention, in one embodiment the piston rod has a diameter of about 0.385 inch, resulting in an effective cross-sectional area above the plunger **81** of about 0.0799 square inches. Thus, the amount of lubricant forced out of the upper chamber **77** through the outlet passage **43** equals the effective cross-sectional area above the plunger **81** (i.e., 0.0799 square inches in the illustrated embodiment) times the stroke length.

Upon completion of an upstroke, the control signals the stepper motor **115** to reverse direction, causing the piston rod **65** and pump core **51** to move through a downstroke. As the pump core **51** moves in a downward direction from the position shown in FIG. **9** to the position shown in FIG. **7**, the volume of the lower chamber **104** decreases. Because the priming check valve **103** has a sealing fit with the shovel rod **101**, the priming check valve closes as the volume of the lower chamber **104** decreases. As the volume of the lower chamber **104** decreases, fluid within that chamber is forced up past the check valves **89**, **93** and into the upper chamber **77** via the longitudinal plunger passage **83** and the lateral passages **85**, **87**. The fluid entering the upper chamber **77** from the lower chamber **104** causes an amount of fluid to move from the upper chamber **77** out through the outlet passage **43**. Although the shovel rod **101** may have other diameters without departing from the scope of the present invention, in one embodiment the shovel rod has a diameter of 0.184. Thus, the effective cross-section area below the plunger **81** is about 0.1698 square inches or a little more than twice the area above the plunger. As will be apparent to those skilled in the art, the amount of lubricant pushed out of the lower chamber **104**, past the check valves **89**, **93** and into the upper chamber **77** equals the effective cross-sectional area below the plunger **81** (i.e., 0.1698 square inches in the illustrated embodiment) times the stroke length or about twice as much as lubricant as forced out of the upper chamber **77** through the outlet passage **43** during the upstroke. The fluid entering the upper chamber **77** during the downstroke causes an amount of fluid to move from the upper chamber **77** out through the outlet passage **43**. In the illustrated embodiment, the amount of lubricant pushed from the upper chamber **77** through the outlet passage **43** during the downstroke equals the difference in the effective cross-sectional areas above and below the plunger **81** times the stroke length or about the same amount of lubricant as pushed through the outlet passage during the upstroke. Accordingly, regardless of whether the motor **115** is moving the piston rod **65** through the upstroke or downstroke, about the same amount of lubricant is pushed through the outlet passage **43**.

Providing the same amount of lubricant during each stroke enables the pump to be used to meter predetermined measured quantities of lubricant. For example, if particular circumstances necessitate delivering a quantity of lubricant equal to that delivered by one stroke of the piston rod **65**, the control **291** signals motor **115** to drive the piston rod through one stroke. If twenty times that quantity is desired, the control signals the motor to operate through twenty strokes to deliver the increased amount.

FIG. **10** is a block diagram illustrating a control **312** controlling a drive mechanism **310** such as a servo motor or a stepper motor driving a lance pump **306** according to one embodiment of the invention. (By way of example, the lance pump **306** may be identical or similar to the lance pump **21** described above.) FIG. **11** is a flow chart illustration operation of the control.

Referring to FIG. **10**, a reservoir **302** holds lubricant and has a reservoir outlet **304** in communication with an input **305** to the lance pump **306**, which has an output **308** in communication with a system (not shown) requiring lubricant. The drive mechanism **310** includes a motor such as a stepper motor or a servo motor for driving the lance pump. The control **312** controls the operation of the motor by selectively varying a current or a voltage applied to the motor to control a speed and/or a torque of the motor to drive the lance pump **306** to dispense lubricant via its output to the system. A pressure sensor **314** (e.g., similar to the pressure sensor **49** of the pump **21** described above) senses a pressure condition at the output of the lance pump **306** and provides a pressure condition signal **316** indicative of the pressure condition. The control **312** is responsive to the pressure condition signal **316** and selectively varies the current or the voltage applied to the motor to vary the speed and/or the torque of the motor as a function of a difference between the pressure condition signal **316** and a target pressure condition stored in a tangible, non-transitory memory **318**. The memory also stores software control instructions executed by the control which may include a processor in one embodiment.

In an embodiment in which the motor comprises a stepper motor, the control **312** selectively applies PWM (pulse width modulated) pulses via a power supply **320** to the stepper motor to vary speed and torque of the stepper motor as a function of the target pressure condition compared to the sensed pressure condition.

In one embodiment, the **312** applies PWM pulses to the stepper motor such that the speed of the stepper motor is a first speed and a first torque when the pressure signal is within a first range. In addition, the control **312** applies PWM pulses to the stepper motor such that the speed of the stepper motor is a second speed less than the first speed and at a second torque greater than the first torque when the pressure signal is within a second range higher than the first range.

In one embodiment, the motor comprises a servo motor and the control **312** selectively applies a varying voltage to the servo motor to vary the speed of the servo motor as a function of the target pressure condition compared to the sensed pressure condition.

For example, the control **312** may apply a voltage and/or current to the servo motor such that the speed of the servo motor is a first speed and at a first torque when the pressure signal is within a first range, and the control **312** applies a voltage and/or current to the servo motor such that the speed of the servo motor is a second speed less than the first speed and at a second torque greater than the first torque when the pressure signal is within a second range higher than the first range.

It is also contemplated as an alternative that a profile as illustrated in FIG. **12** or an algorithm for controlling the speed or torque of the motor may be stored in the memory **318** and that the control **312** controls the speed or torque of the motor as a function of the profile or algorithm. In one embodiment, the target pressure stored in memory **318** is 4000 PSI and the control instructions in the memory **318** are executed by the control to maximize the lubricant flow and pressure at or below 4000 PSI without stalling the motor. For example, the motor speed (voltage) would be operated as fast as possible and/or the motor current with as much torque as possible without stalling the motor and without saturating the motor stator (e.g., the motor is operated below its stall curve **500** illustrated in FIG. **12**). As the pressure increases, the speed of the motor would be decreased and the torque of the motor would be increased. In addition, the motor is operated such that the motor temperature is maintained within its operating range.

When the drive mechanism **310** includes a stepper motor, one embodiment includes control instructions in memory **318** executed by control **312** resulting in the frequency of PWM pulses applied to the stepper motor decreasing and the pulse width increasing to decrease speed and increase torque as the pressure of the lubricant increases, as indicated by pressure signal **316**. The frequency of the pulses applied to the stepper motor would be maintained above a minimum and the width of the pulses would be maintained below a maximum to prevent stalling and to minimize motor temperature. When the drive mechanism **310** includes a servo motor, one embodiment includes control instructions in memory **318** executed by control **312** resulting in decreasing the voltage applied to the servo motor and increasing the current applied to the servo motor as the pressure increases. The servo motor may have an encoder which provides feedback to the control **312** indicative of the speed of the servo motor. The voltage applied to the servo motor would be maintained above a minimum and the current applied would be maintained below a maximum to prevent stalling and to maintain the motor temperature within its operating range.

FIG. **11** illustrates one embodiment of a method for supplying lubricant to a system and illustrates one embodiment of software instruction stored in memory **318**. The method includes providing a reservoir **302** for holding lubricant. A lance pump **306** having an input **305** in communication with a reservoir outlet **304** and having an output **308** in communication with the system is also provided. A drive mechanism **310** including a motor comprising a variable speed motor, such as a stepper motor or a servo motor, drives the lance pump **306**. The operation of the motor is controlled by selectively varying the current or voltage applied to the motor to control a speed and/or a torque of the motor to drive the lance pump **306** to dispense lubricant via its output **308** to the system. A pressure condition at the output **308** of the lance pump **306** is sensed at **402** and compared at **404** a pressure condition signal **316** indicative of the pressure condition. The current or voltage applied to the motor is selectively varied to vary the speed and/or the torque of the motor as a function of a difference between the pressure condition signal **316** and a target pressure condition stored in memory **318**.

When the motor comprises a stepper motor, PWM pulses are selectively applied to the stepper motor to vary speed and torque of the stepper motor as a function of the target pressure condition compared to the sensed pressure condition.

In one embodiment, when a difference between the sensed pressure at **402** compared to the target pressure at **404** is within a first range at **406**, the PWM pulses are applied to the stepper motor at **408** such that the stepper motor is at a first speed and at a first torque. When the difference at **410** is within a second range higher than the first range, PWM pulses are applied to the stepper motor at **412** such that the stepper motor is at a second speed less than the first speed and at a second torque greater than the first torque.

When the motor comprises a servo motor, the control **312** selectively applies a varying voltage to the servo motor to vary speed of the servo motor as a function of the target pressure condition stored in memory **318** compared to the sensed pressure condition **316**. In particular, a voltage is applied to the servo motor such that the speed of the servo motor is a first speed and at a first torque when the pressure signal is within a first range, and a voltage to the servo motor such that the speed of the servo motor is a second speed less than the first speed and at a second torque greater than the first torque when the pressure signal is within a second range higher than the first range.

As a result of the motor operation as described above, the pressure of lubricant supplied to a system via output **308** is ramped up and maintained close or slightly below the target pressure stored in memory **318**. Simultaneously, the volume of lubricant pumped over time is decreased as the pressure increases to avoid excessive pressure and to minimize the release of lubricant via a safety or relief valve of the system. This inhibits excessive back pressure, minimizes motor stalls and promotes more lubricant to be quickly and effectively supplied to the system. As a result, the system and its components are effectively lubricated and the risk of failure due to improperly lubricated components of the system is minimized.

As will be appreciated by those skilled in the art, the lance pump **21** described above has several advantages over many prior commercially available lance pumps. Because the lance pump **21** is driven by a stepper motor capable of turning its output shaft at variable speeds, the output pressure and flow rate provided by the pump can be varied to conform to demand or specific operating conditions and environments. The lance pump is capable of providing viscous liquids at desired pressures on demand. Further, because the motor can run at lower speeds, complicated reduction gearing such as found in some prior commercial lance pumps can be eliminated. It is envisioned that by eliminating the reduction gearing, the cost and complexity of the lance pump may be reduced compared to lance pumps having reduction gearing.

As will be appreciated by those skilled in the art, the lance pump described above may be used in place of other types of lubricant pumps such as those described in U.S. patent application Ser. No. 13/271,862 filed Oct. 12, 2011, entitled, "Pump having Stepper Motor and Overdrive Control," which is incorporated by reference. In such an application the pump can be to provide substantial lubricant flow (e.g., 150 cc/min) during system start up when pressures are low (e.g., 0 psi) and reduced flow after start up (e.g., 10 cc/min) when lubricant pressures are higher (e.g., 5000 psi).

As will also be appreciated by those skilled in the art, the motor may be a servo motor rather than a stepper motor and the control can be modified accordingly.

Having described the invention in detail, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims.

When introducing elements of the present invention or the preferred embodiments(s) thereof, the articles "a", "an", "the", and "said" are intended to mean that there are one or more of the elements. The terms "comprising", "including", and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A pressure controlled pump for pumping a viscous liquid from a reservoir, said pump comprising:

a pump body adapted for positioning above said reservoir;

an elongate tube extending downward from an upper end connected to the body, past an upper portion and a lower portion, to a lower end when the body is positioned above said reservoir;

an elongate core slidably received in the tube and extending vertically downward from the body into the liquid when the body is in position above the reservoir, the core having a longitudinal axis extending between an upper end mounted on the body and a lower end opposite the upper end;

a stepper motor mounted on the body having a selectively rotatable output shaft extending vertically above the liquid in the reservoir when the body is in position;

a transmission operatively connected to the stepper motor output shaft for effecting reciprocating relative motion between the tube and the core so the elongate core moves between a relative raised position and a relative lowered position as the stepper motor output shaft rotates in one direction to effect an upward pumping stroke and in an opposite direction to effect a downward pumping stroke;

an inlet check valve mounted inside the tube defining with the tube an expansible and contractible lower pump chamber, the inlet check valve being oriented to open during each upward pumping stroke permitting viscous liquid to enter said lower pump chamber;

an annular upper chamber defined in part by the tube and the core above the lower pump chamber and having a cross-sectional area half as large as that of said lower pump chamber;

a lateral passage in the core connecting the lower pump chamber to the annular upper chamber having a check valve oriented to open during each downward pumping stroke;

an outlet passage connected to the annular upper chamber so viscous liquid flows from the annular upper chamber and through the outlet passage during each upward pumping stroke and each downward pumping stroke;

a pressure monitor in fluid communication with liquid in the outlet passage for measuring pressure of said liquid; and a control operatively connected between the pressure monitor and the stepper motor for controlling operation of the stepper motor in response to a signal from the pressure monitor, the control adjusting stepper motor output shaft speed in response to the signal from the pressure monitor, said control controlling operation of the stepper motor to deliver a predetermined quantity of viscous liquid through the outlet by effecting a selected number of upward pumping strokes and downward pumping strokes, said control thereby delivering the predetermined quantity of viscous liquid at a preselected pressure.

2. A pump as set forth in claim **1**, wherein the control adjusts output shaft speed to maintain pressure sensed by the pressure monitor to be in a range from about 1000 psi to about 5000 psi.

3. A pump as set forth in claim **1**, wherein:

the transmission operatively connects the stepper motor output shaft and the elongate core; and

the transmission reciprocates the core between a raised position and lowered position.

4. A pump for pumping a viscous liquid from a reservoir, said pump comprising:

a pump body adapted for positioning above said reservoir;

an elongate tube extending downward from an upper end connected to the body to a lower end below the upper end when the body is positioned above said reservoir;

an elongate core slidably received in the tube and extending vertically downward from the body into the liquid when the body is in position above the reservoir, the core having a longitudinal axis extending between an upper end mounted on the body and a lower end opposite the upper end;

an electric stepper motor mounted on the body having a selectively rotatable output shaft for effecting relative reciprocating motion between the core and the elongate tube so the core moves between a relative raised position and a relative lowered position as the motor output shaft rotates in one direction to effect an upward pumping stroke and in an opposite direction to effect a downward pumping stroke;

a control operatively connected to the electric stepper motor for controlling operation of the motor, said control adjusting stepper motor output shaft speed in response to at least one characteristic of liquid in the pump, said control controlling operation of the stepper motor to deliver a predetermined quantity of viscous liquid through the outlet by effecting a selected number of upward pumping strokes and downward pumping strokes, said control thereby delivering the predetermined quantity of viscous liquid having the at least one characteristic;

an inlet check valve mounted inside the tube defining with the tube an expansible and contractible lower pump chamber, the inlet check valve being oriented to open during each upward pumping stroke permitting viscous liquid to enter said lower pump chamber;

an annular upper chamber defined in part by the tube and the core above the lower pump chamber and having a cross-sectional area half as large as that of said lower pump chamber;

a lateral passage in the core connecting the lower pump chamber to the annular upper chamber having a check valve oriented to open during each downward pumping stroke to deliver viscous liquid from the lower pump chamber to the annular upper chamber; and

an outlet passage connected to the annular upper chamber permitting viscous liquid to flow from the annular upper chamber.

5. A pump as set forth in claim **4**, wherein the control adjusts output shaft speed in response to at least one characteristic of liquid in the pump selected from a group of characteristics consisting of pressure and flow rate.

6. A pump as set forth in claim **5**, wherein the control adjusts output shaft speed in response to liquid pressure in the pump.

7. A pump as set forth in claim **6**, further comprising a pressure monitor in fluid communication with liquid in the pump downstream from the check valve for measuring pressure of the liquid and providing a signal to the control corresponding to the measured pressure.

8. A pump as set forth in claim **7**, wherein the pressure monitor is mounted for sensing pressure of liquid in the outlet passage.

9. A pump as set forth in claim **8**, wherein the control adjusts output shaft speed to maintain pressure sensed by the pressure monitor to be in a range of about 1000 psi to about 5000 psi.

10. A pump as set forth in claim **4**, wherein the motor reciprocates the core between a raised position and lowered position.

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